NS102 Lecture 14

Open: *Verklärte Nacht*
(Transfigured Night)
Arnold Schoenberg

Look, how brightly the universe shines!
Splendour falls on everything around,
You are voyaging with me on a cold sea,
But there is the glow of an inner warmth
From you in me, from me in you.

This is <u>not</u> the big bang!

Close: *Champagne Supernova*
Oasis

GnatSigh News
(all the news that fits)

- **Website**

  http://home.fnal.gov/~rocky/NS102/

- **Exam next Tuesday**

Lab this week: The Hubble constant
Lab next week: Big Bang Nucleosynthesis

We are not the center of the expansion of the universe

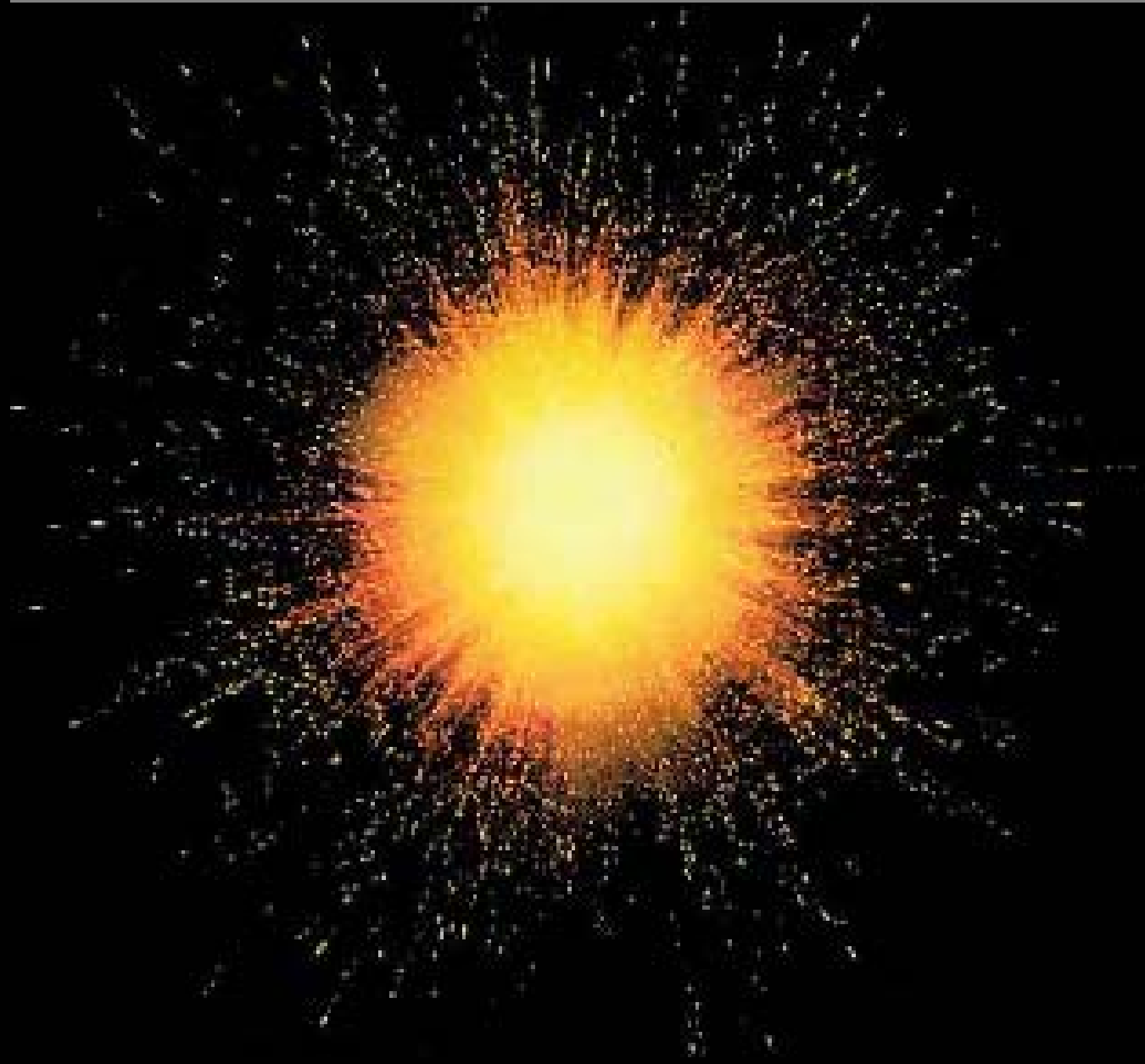
Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe (no center)
- no special set of points (no edge)

This is not the big bang!

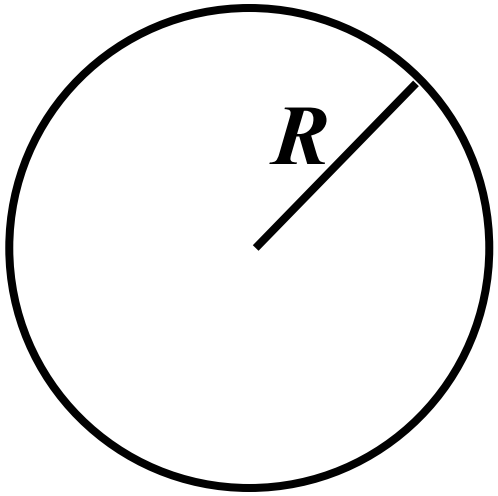


Spaces that obey the cosmological principle:

1-dimension:

^1R  x

$$V = \int_{-\infty}^{\infty} dx = \infty$$

^1S 

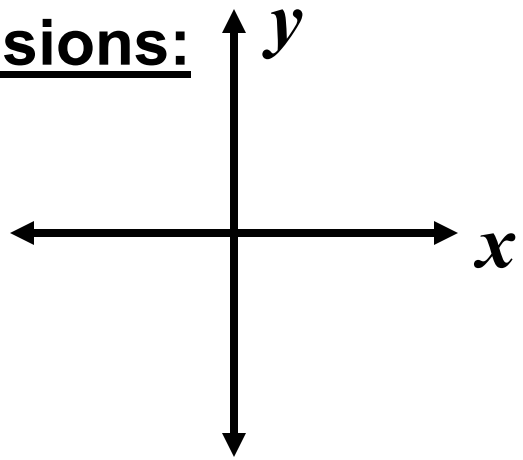
$$V = R\int_0^{2\pi} d\phi = 2\pi R$$

$$x^2 + y^2 = R^2$$

Spaces that obey the cosmological principle:

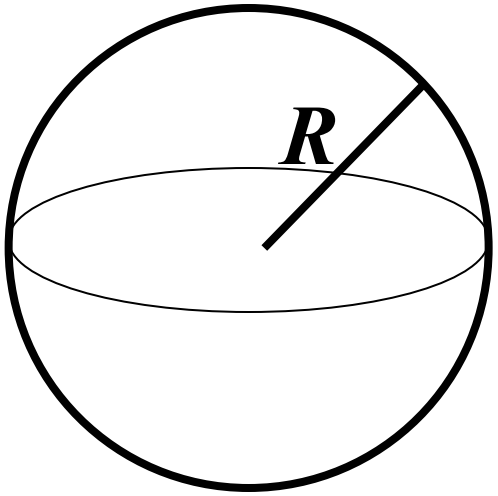
2-dimensions:

^2R



$$V = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy = \infty$$

^2S



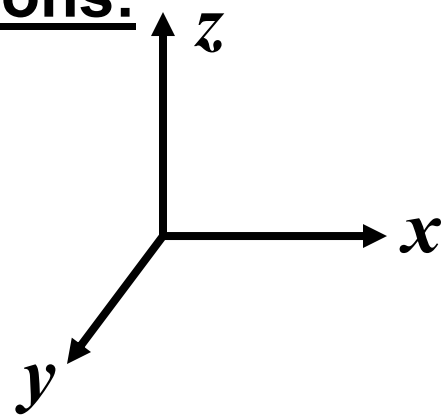
$$V = R^2 \int_0^{\pi} \sin\theta \, d\theta \int_0^{2\pi} d\phi = 4\pi R^2$$

$$x^2 + y^2 + z^2 = R^2$$

Spaces that obey the cosmological principle:

3-dimensions:

^3R

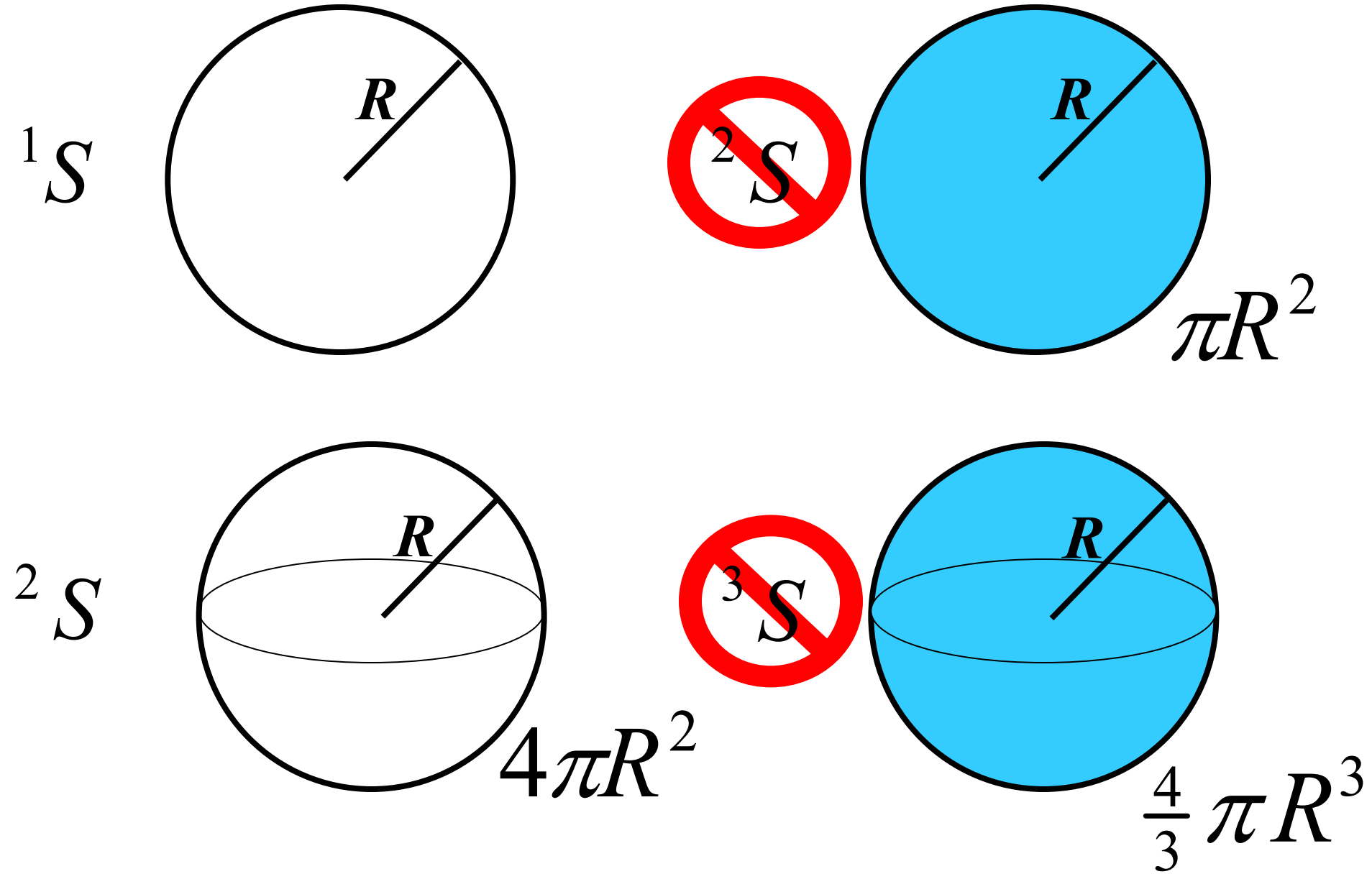


$$V = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy \int_{-\infty}^{\infty} dz = \infty$$

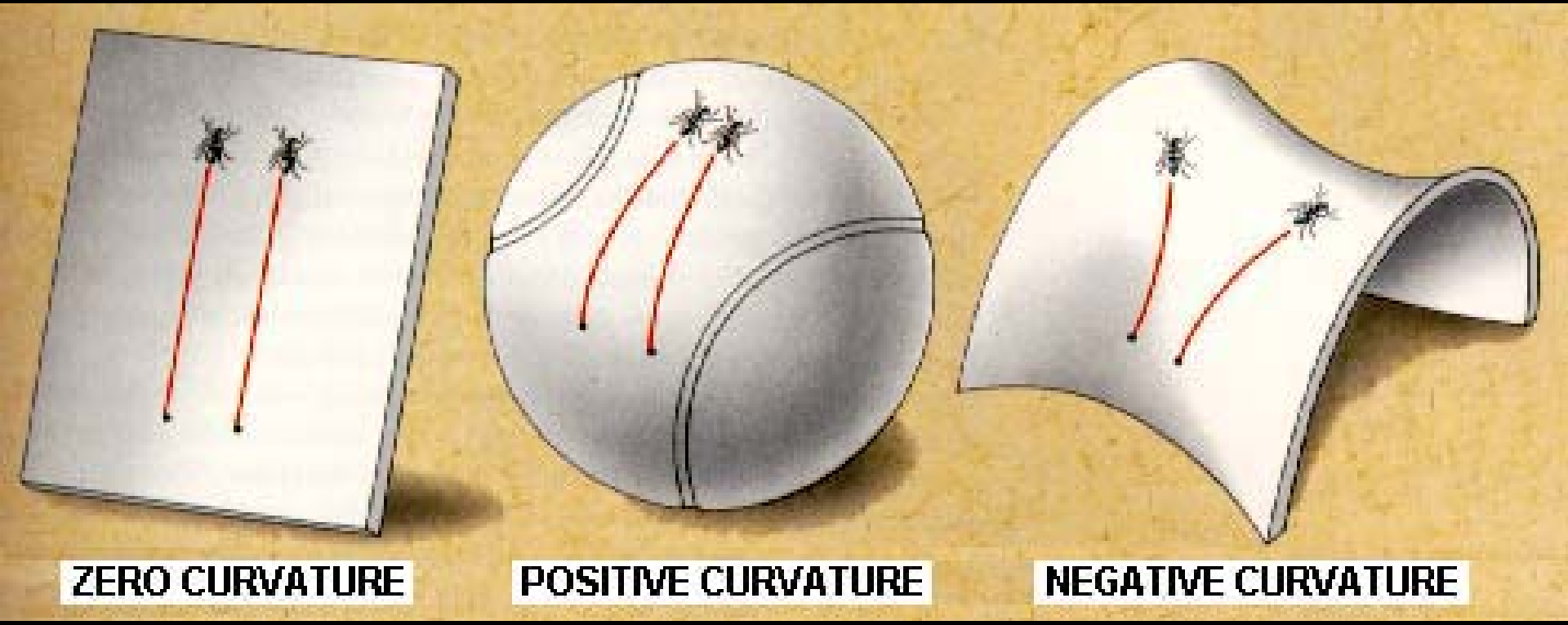
^3S

$$V = R^3 \int_0^{\pi} \sin^2 \chi \, d\chi \int_0^{\pi} \sin\theta \, d\theta \int_0^{2\pi} d\phi = 2\pi^2 R^3$$

$$x^2 + y^2 + z^2 + w^2 = R^2$$


^1S
R
^2S
R
πR^2
^2S
R
$4\pi R^2$
^3S
R
$\frac{4}{3}\pi R^3$

^3R ^3S ^3H



FLAT SPHERICAL HYPERBOLIC

The expansion of the universe is

an explosion *of* space

not

an explosion *into* space

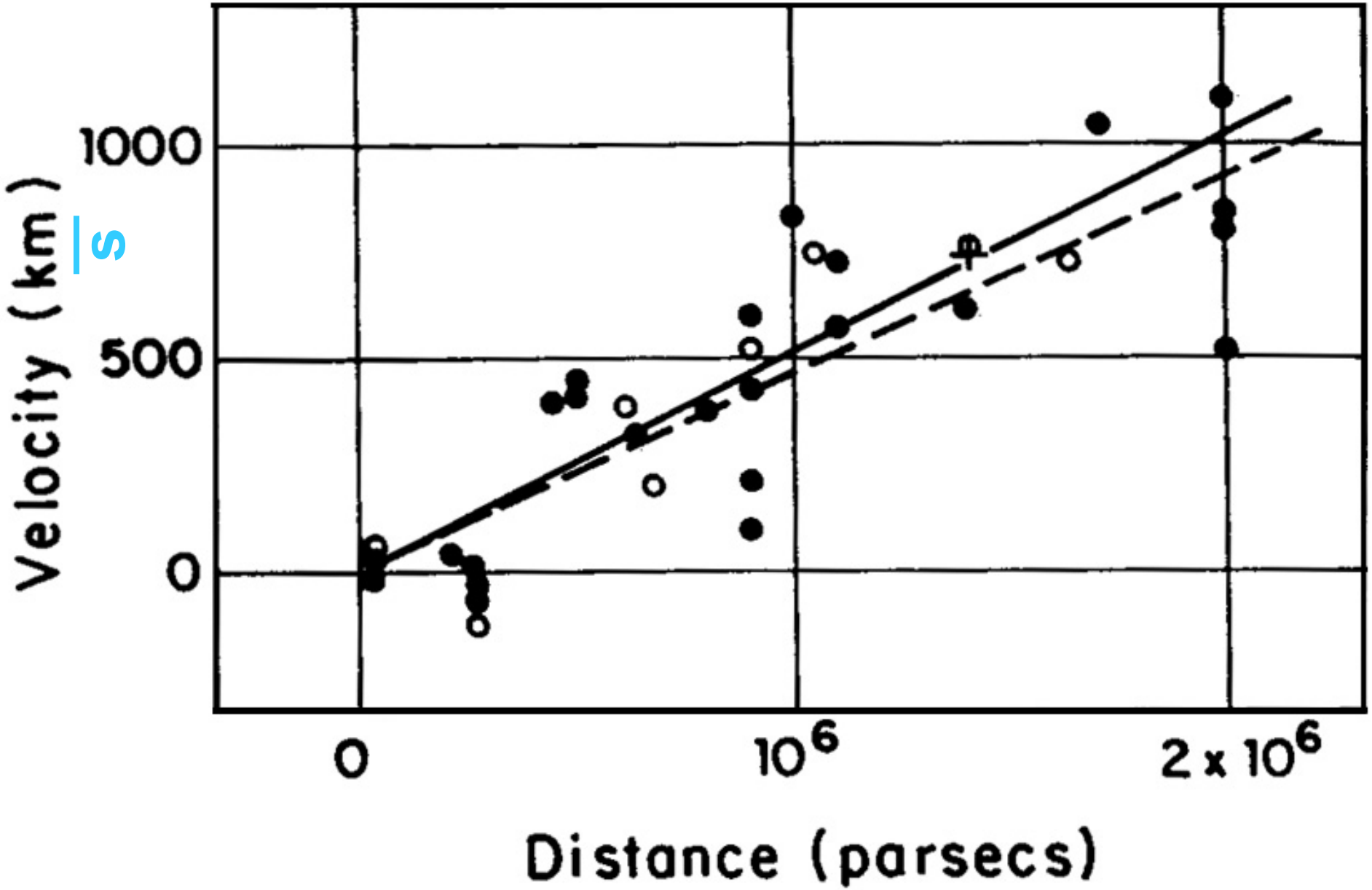
Into what does space expand?

The big bang is an expansion of space

The universe does not expand *into* anything!

This is not the big bang!

Hubble's Discovery Paper - 1929

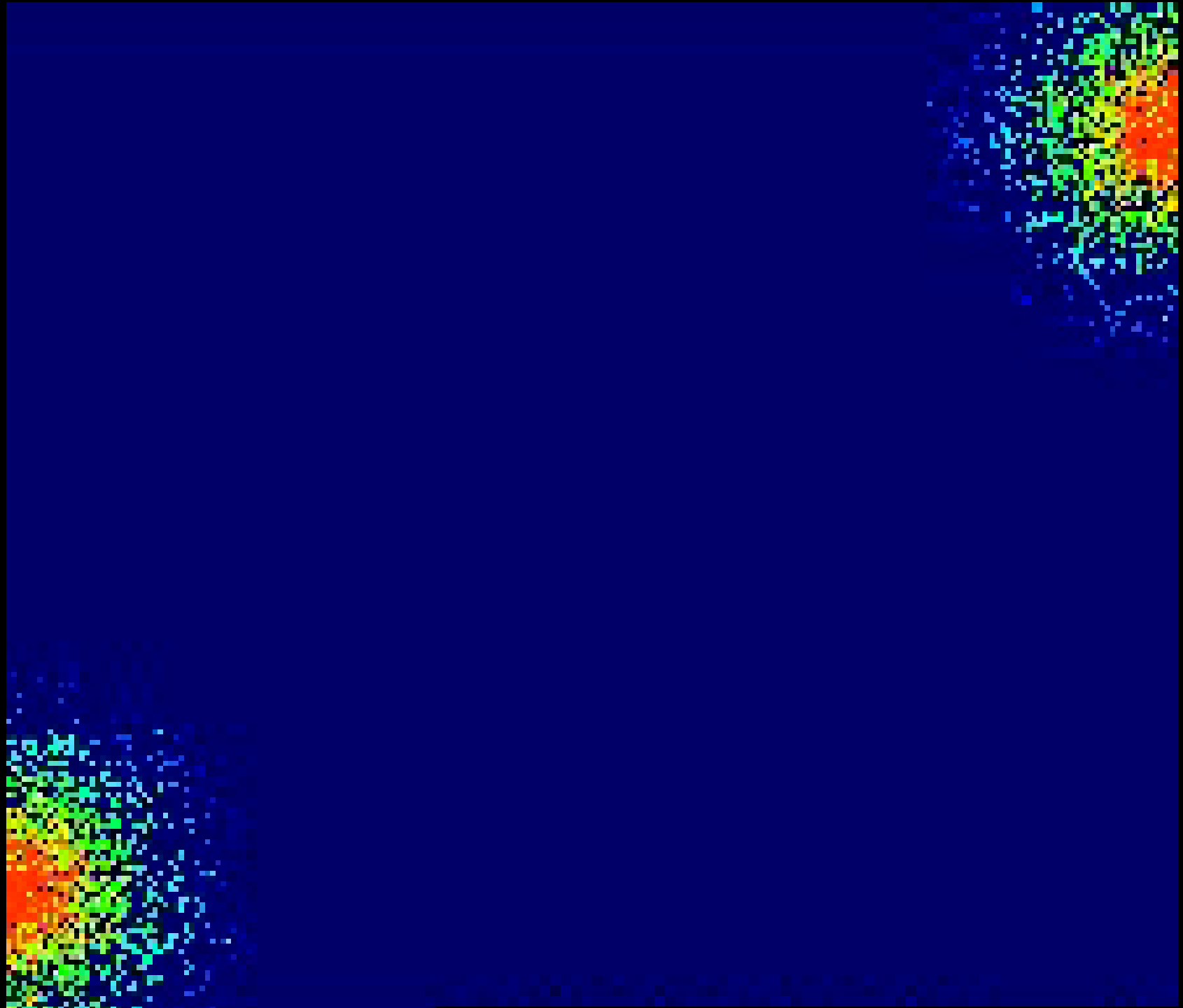


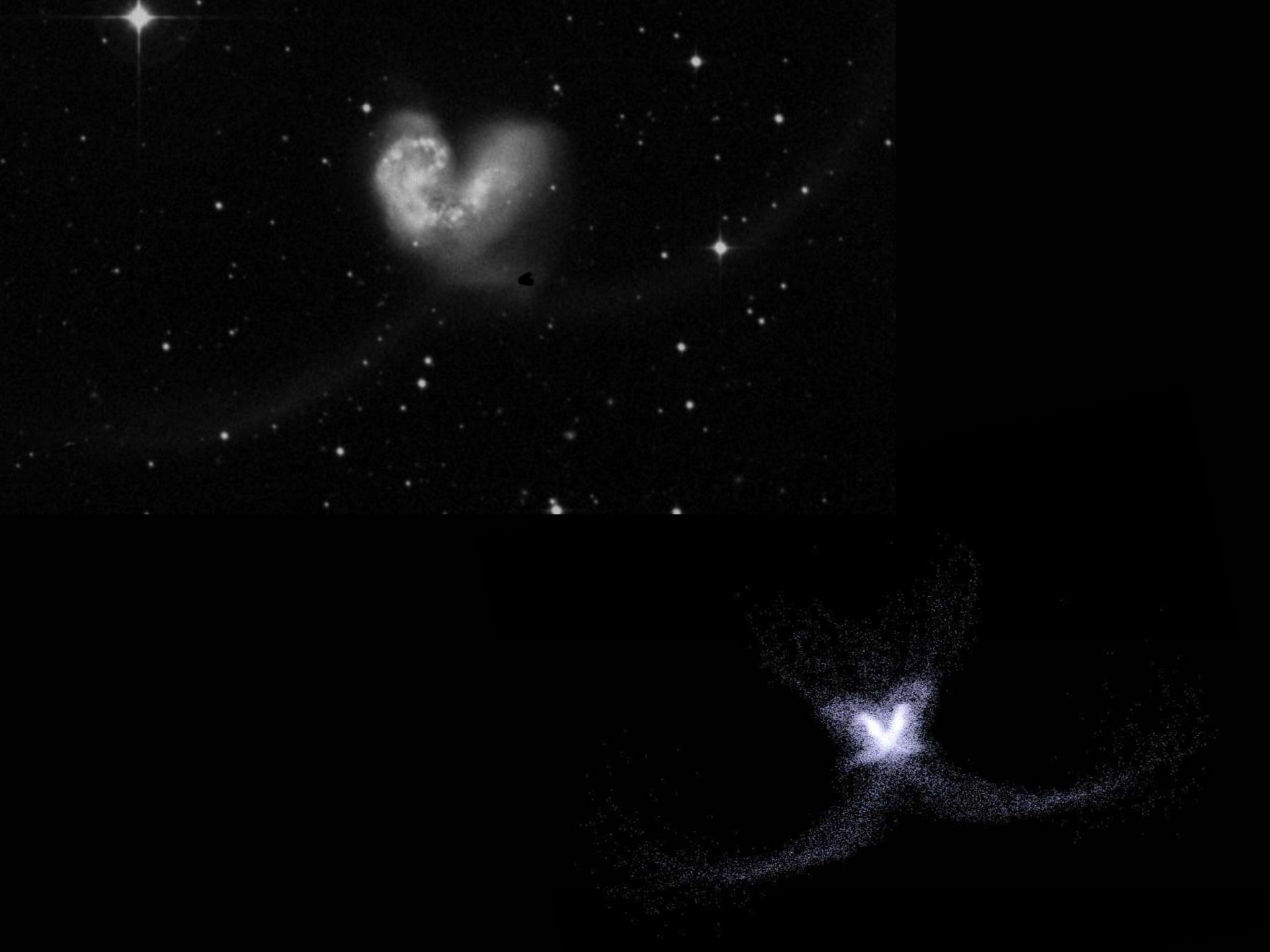
A blue shift for nearby galaxies?

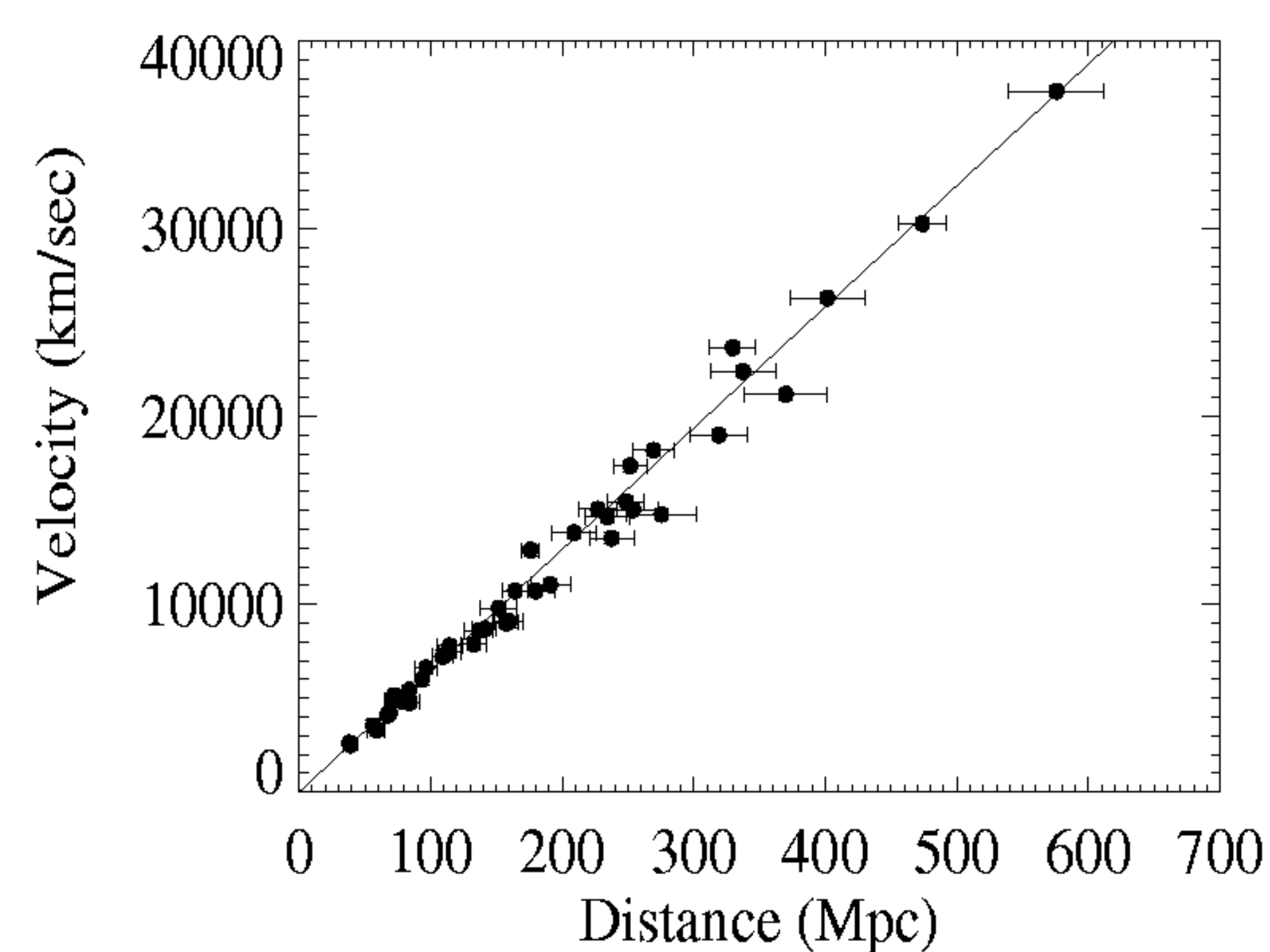
blueshift = 300 km s^{-1}
distance = 0.65 Mpc

$$300\frac{\text{km}}{\text{sec}}\times\frac{3\times10^{7}\text{sec}}{\text{yr}}\times\frac{1\text{Mpc}}{3\times10^{19}\text{km}}$$

$$=\frac{1\text{ Mpc}}{3\text{ Gyr}}\Rightarrow 0.65\text{ Mpc in 2 Gyr}$$






40000
30000
20000
10000
0
Velocity (km/sec)
0
100
200
300
400
500
600
700
Distance (Mpc)

We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

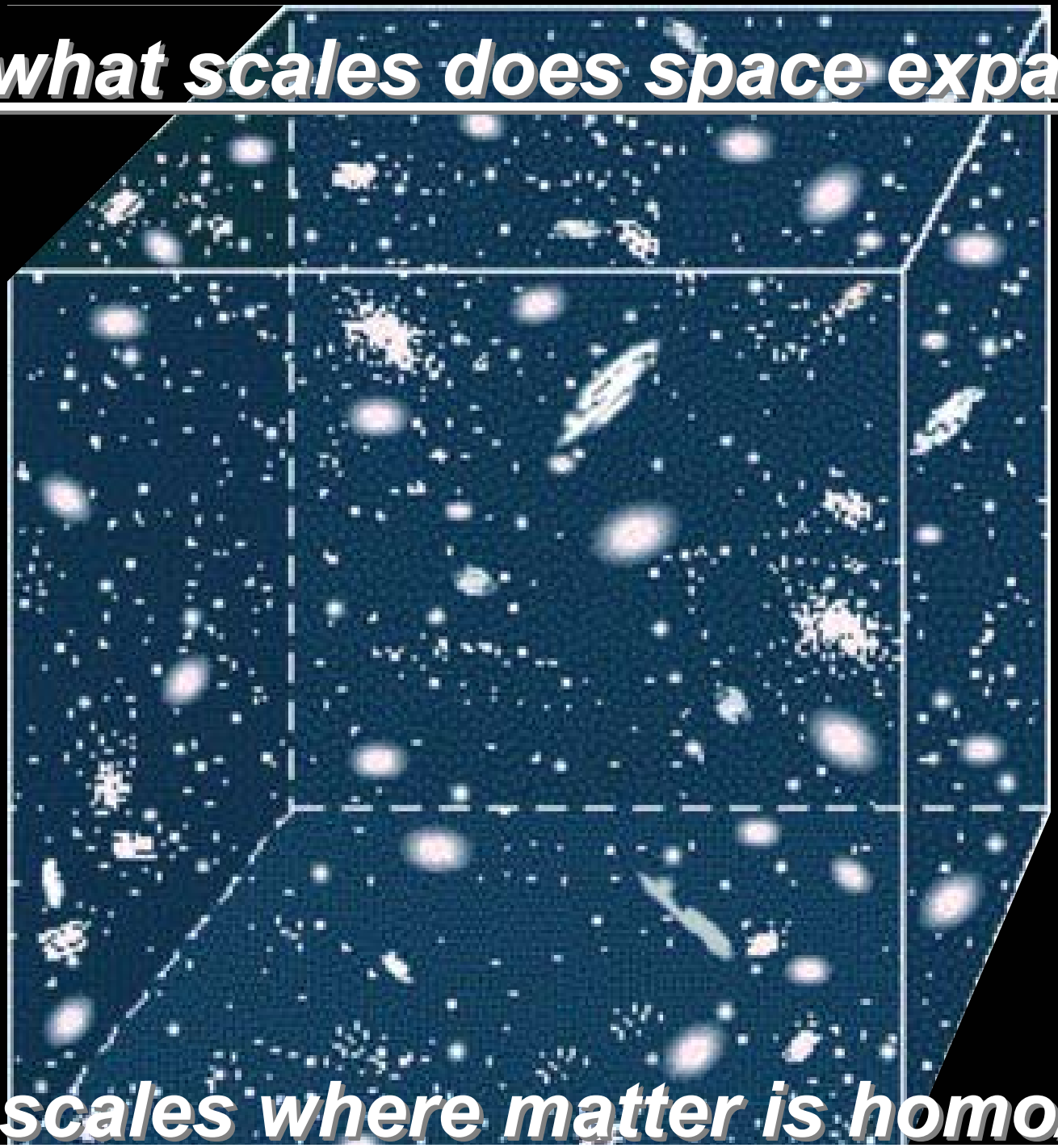
The universe (on large scales) is the same everywhere

- no special point in the universe (no center)
- no special set of points (no edge)

The universe (on large scales) is homogeneous & isotropic

- homogeneous: the same at every point
- isotropic: the same in every direction

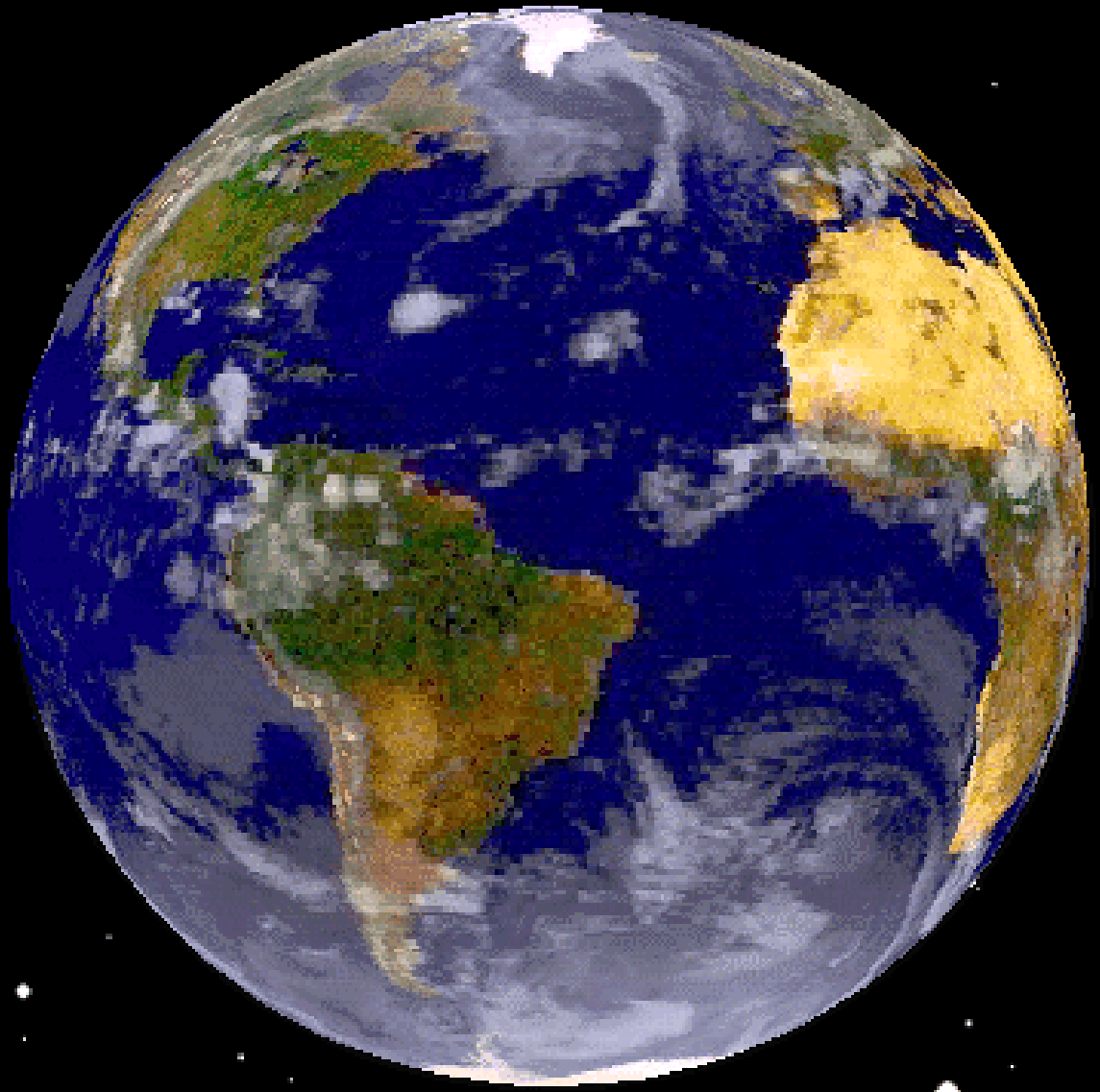
On what scales does space expand?



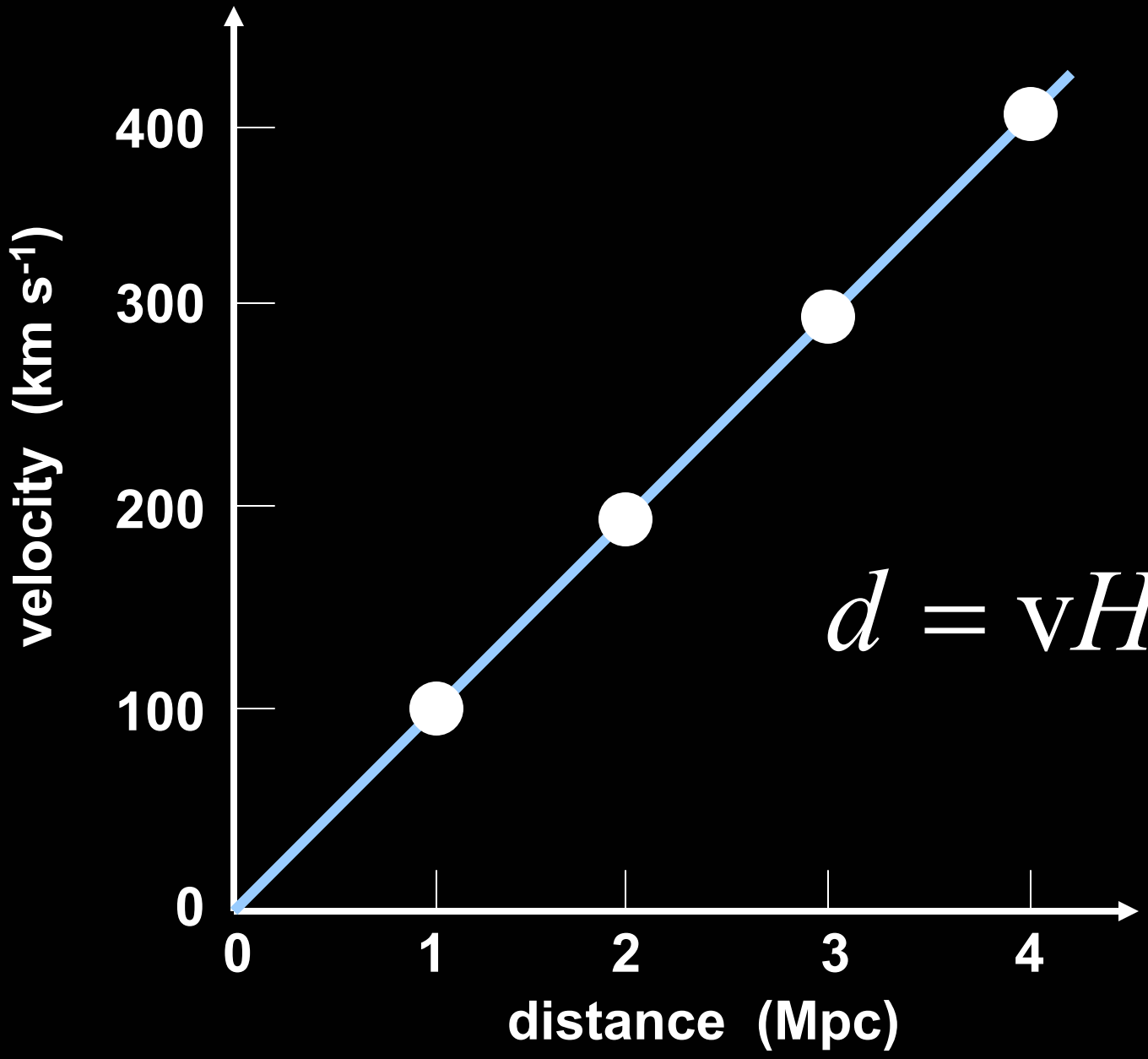
On scales where matter is homo/iso


No net gravitational force…
space experiences
“homogeneity & isotropy”

It ain't homo/iso around here!



Hubble's Law: $v = H_0 d$ $(H_0 = 100h$ km s^{-1} Mpc$^{-1})$



The Hubble age of the universe

$$d = \mathrm{v}t \qquad \text{distance} = \text{velocity} \times \text{time}$$

$$d = \mathrm{v}H_0^{-1} \quad \text{Hubble's law}$$

$$\Big\} \; t = H_0^{-1}$$

$$H_0 = 100h \ \mathrm{km}\,\mathrm{s}^{-1}\,\mathrm{Mpc}^{-1} \times \frac{1\ \mathrm{Mpc}}{3\times10^{19}\ \mathrm{km}}$$

$$(0.8 \geq h \geq 0.6)$$

$$= \frac{100h}{3\times10^{19}}\,\mathrm{s} \times \frac{3\times10^{7}\ \mathrm{s}}{1\ \mathrm{year}}$$

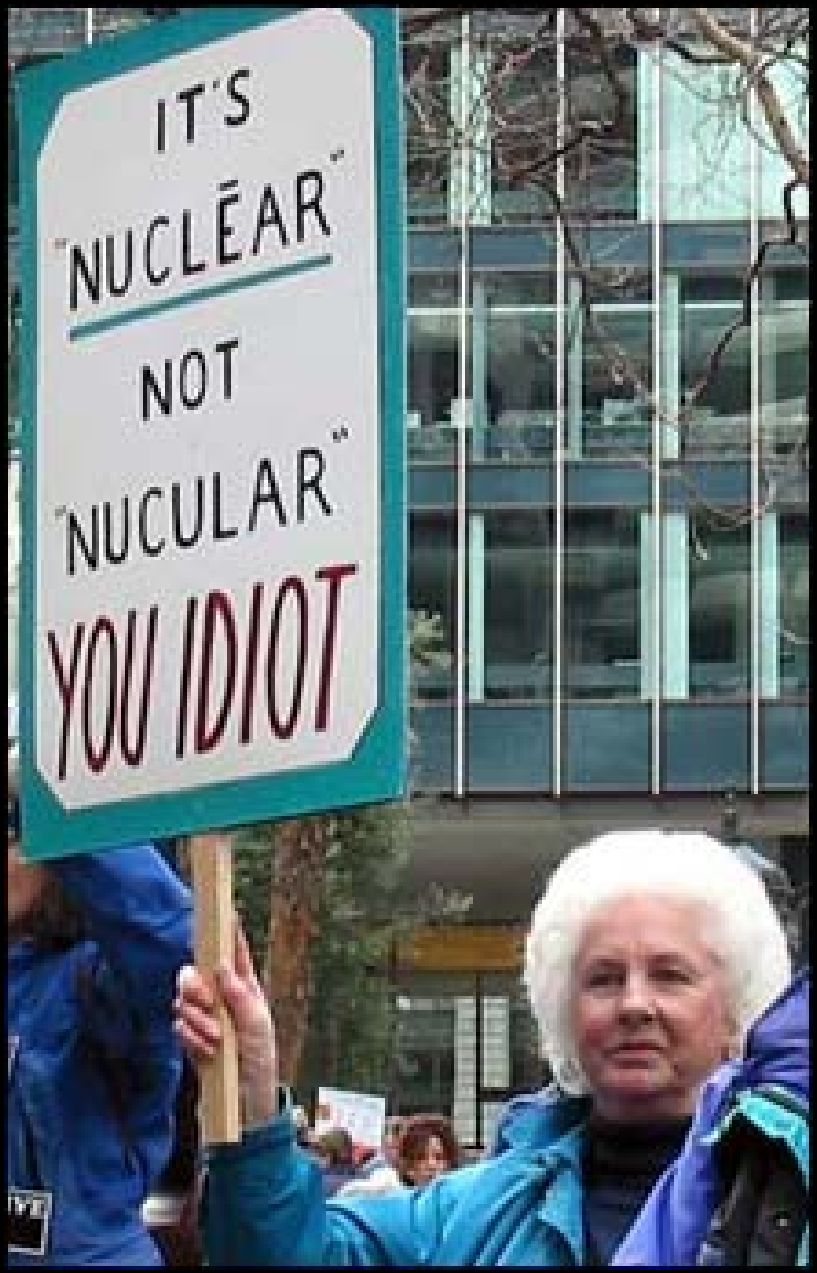
$$= \frac{100h}{10^{12}\ \mathrm{years}} = \frac{h}{10^{10}\ \mathrm{years}}$$

$$t = 10^{10}\,h^{-1}\ \mathrm{years}$$

$$12.5 \leq t \leq 17\ \mathrm{Gyr}$$

$$1\ \mathrm{Gyr} = 10^{9}\ \mathrm{years}$$

Nuclear Physics

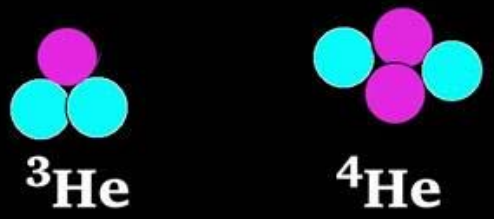


Nucleus made of

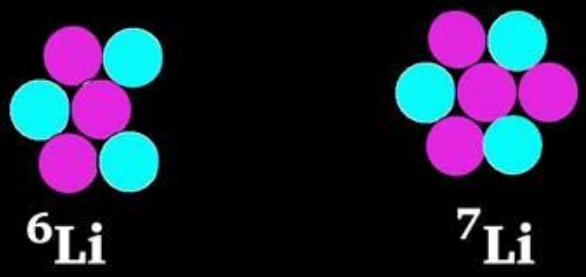
- protons – charge = +1
- neutrons – charge = 0

Hydrogen
1 proton

Helium
2 protons



Lithium
3 protons



The age of the elements

- Elements come in different isotopes
  (same # of protons, different number of neutrons)
- Many isotopes are radioactive — they decay
- If start with $N(0)$ nuclei, after a time *t*, the number will be

$$N(t) = N(0)\, 2^{-t/\tau_{1/2}}$$

$\tau_{1/2}$ is the half-life

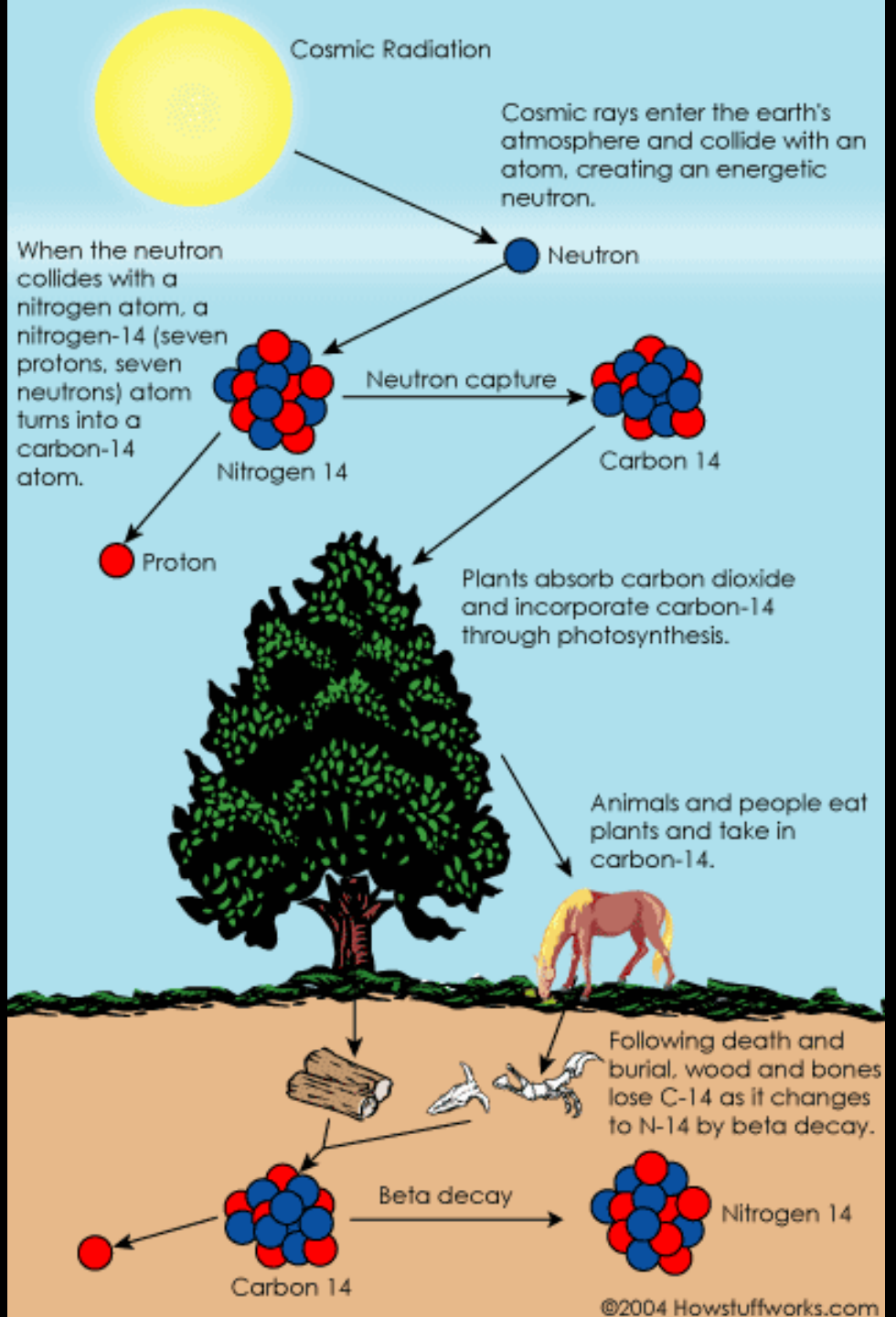
Can use radioactive isotopes to date objects
Radio dating …. nucleocosmochronology

Radiodating ^{14}C

Carbon has 6 protons
Nitrogen has 7 protons

$$n + {}^{14}\mathrm{N} \rightarrow p + {}^{14}\mathrm{C}$$

$${}^{14}\mathrm{C} \rightarrow \mathrm{e}^{-} + {}^{14}\mathrm{N}$$



Moral: use an isotope with appropriate half-life

Appropriate: half-life approximately the age of the sample

$$\tau_{1/2}(^{238}\mathrm{U}) = 4.5\,\mathrm{Gyr}$$

$$\tau_{1/2}(^{187}\mathrm{Re}) = 40\,\mathrm{Gyr}$$

$$\tau_{1/2}(^{232}\mathrm{Th}) = 14\,\mathrm{Gyr}$$

Age of the elements 10 – 18 Gyr

$$t = 10^{10}\,h^{-1}\ \text{years}$$

$$12.5 \le t \le 17\,\mathrm{Gyr}$$

$$1\,\mathrm{Gyr} = 10^{9}\ \text{years}$$

Hubble's original value:

$$H_0 = 500\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

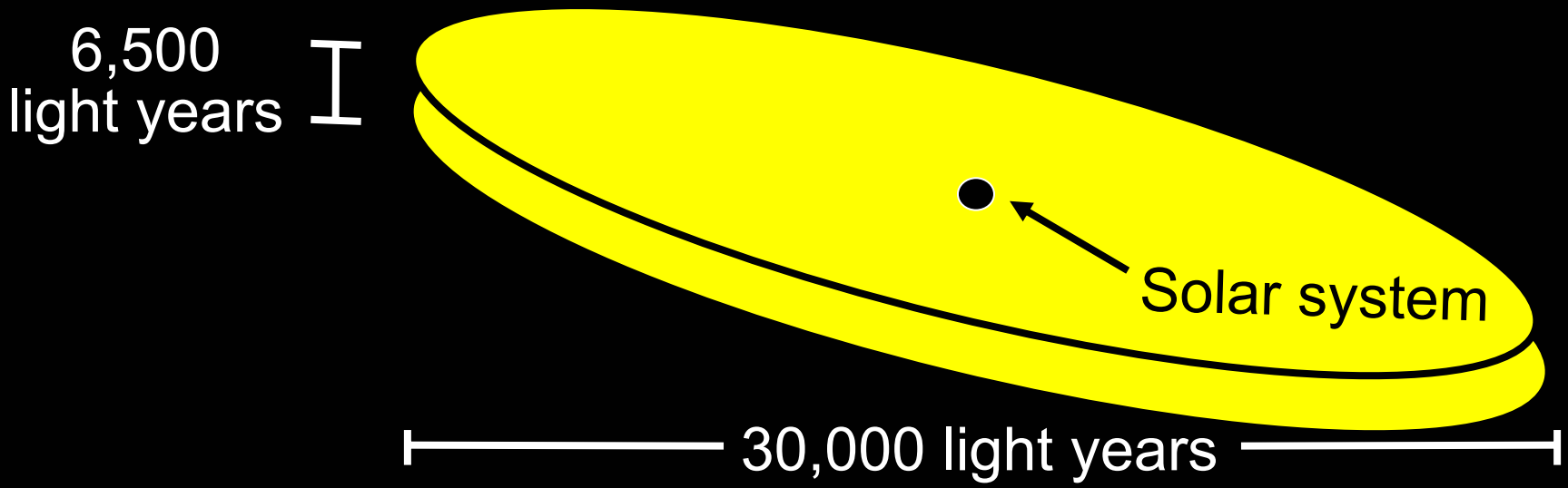
$$h = 5$$

$$t = 10^{10}\,h^{-1}\ \text{years}$$

$$t = 2\,\mathrm{Gyr}$$

A view of the universe, circa 1905

1) Arrangement:



2) Composition: Starz' in the 'hood

3) Static (unchanging in time)

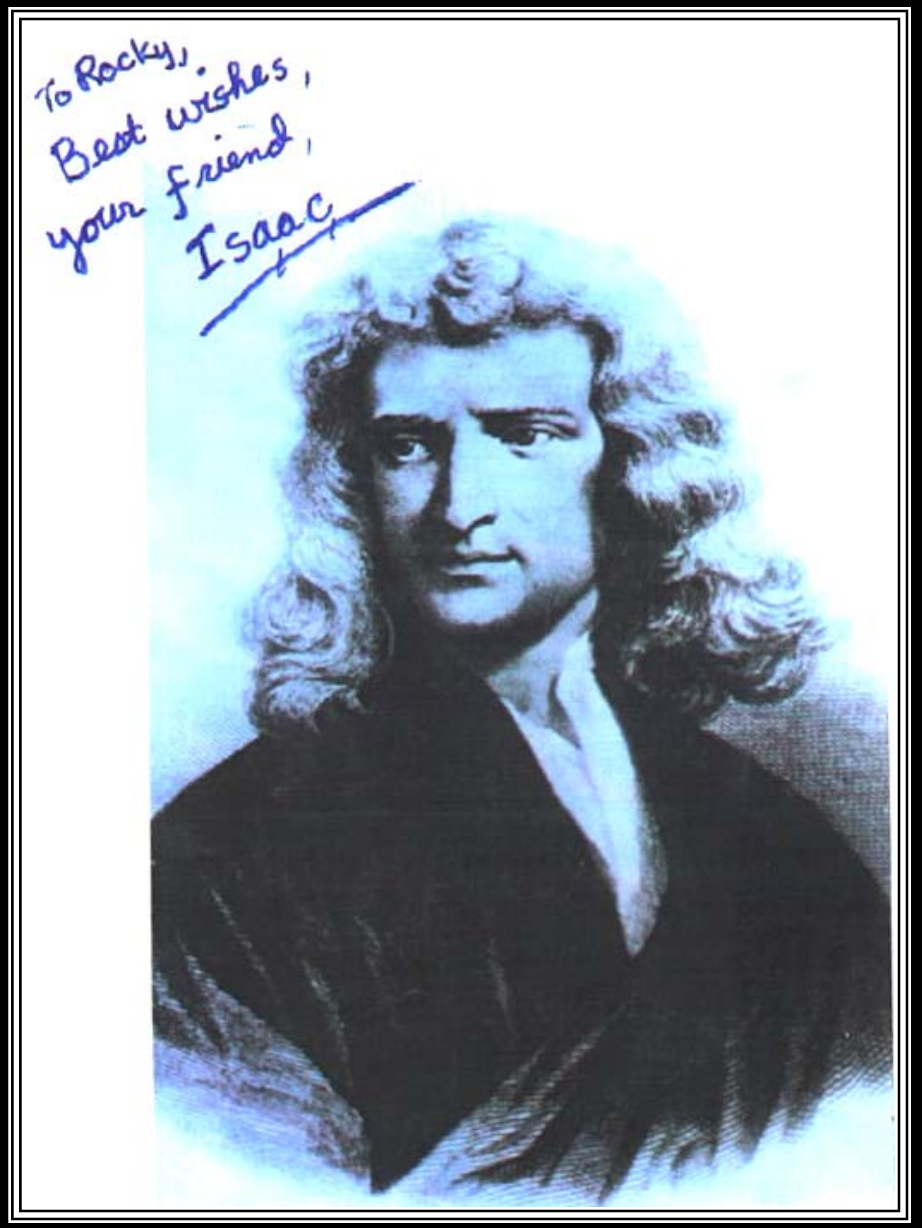
4) Origin???

5) Space and time are absolute

Space and Time Before Einstein

Absolute space,
in its own nature,
without relation
to anything external,
remains always similar
and immovable.

Isaac Newton
1687
Philosophiae Naturalis
Principia Mathematica



"When the Special Theory of Relativity began to germinate in me, I was visited by all sorts of nervous conflicts... I used to go away for weeks in a state of confusion."

"A storm broke loose in my mind."

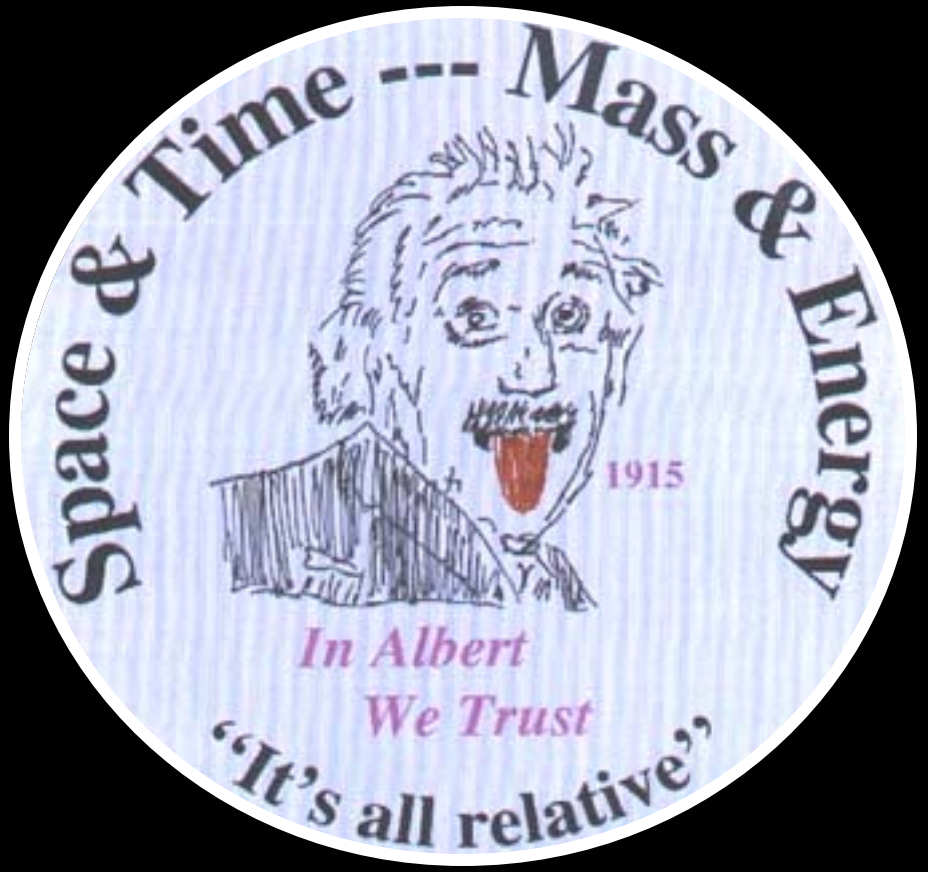
Einstein, ca. 1905

Space and time
are related.

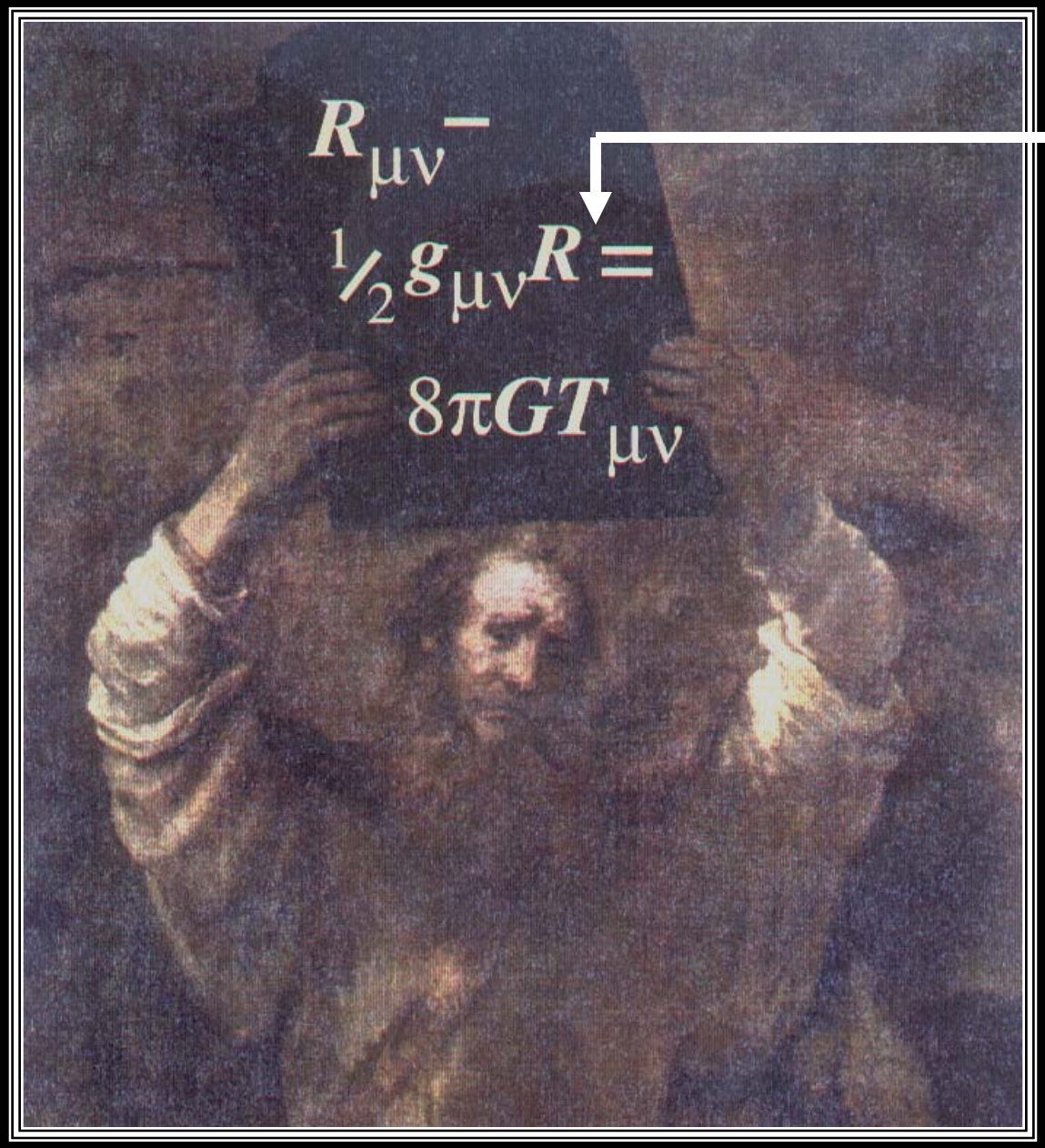
Albert Einstein
1905

Space is dynamical
(curved, warped, bent).

Albert Einstein
1915



Modern Laws of Genesis



Einstein's cosmic legacy

The origin and structure of the universe are amenable to human inquiry!

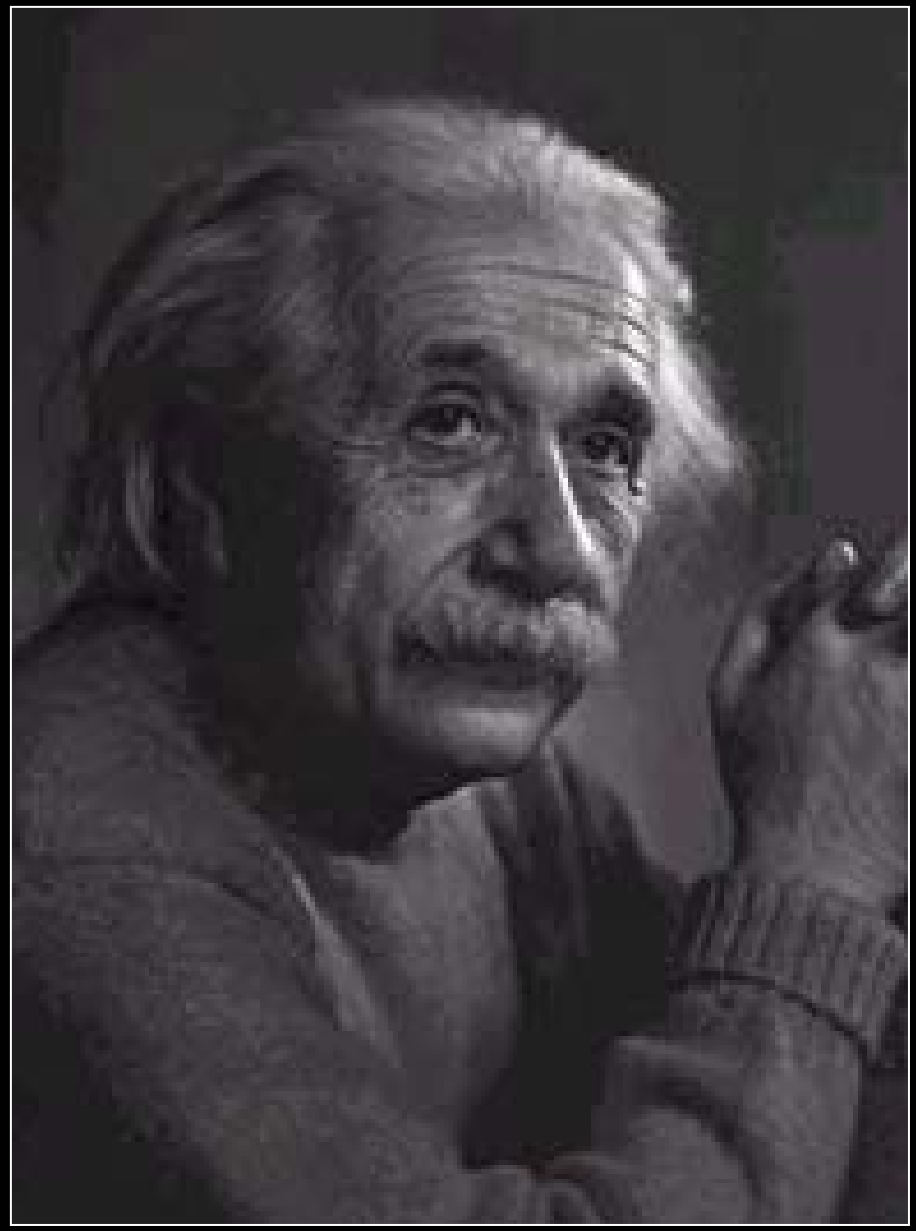
Dark energy

1917 Einstein proposed cosmological constant.

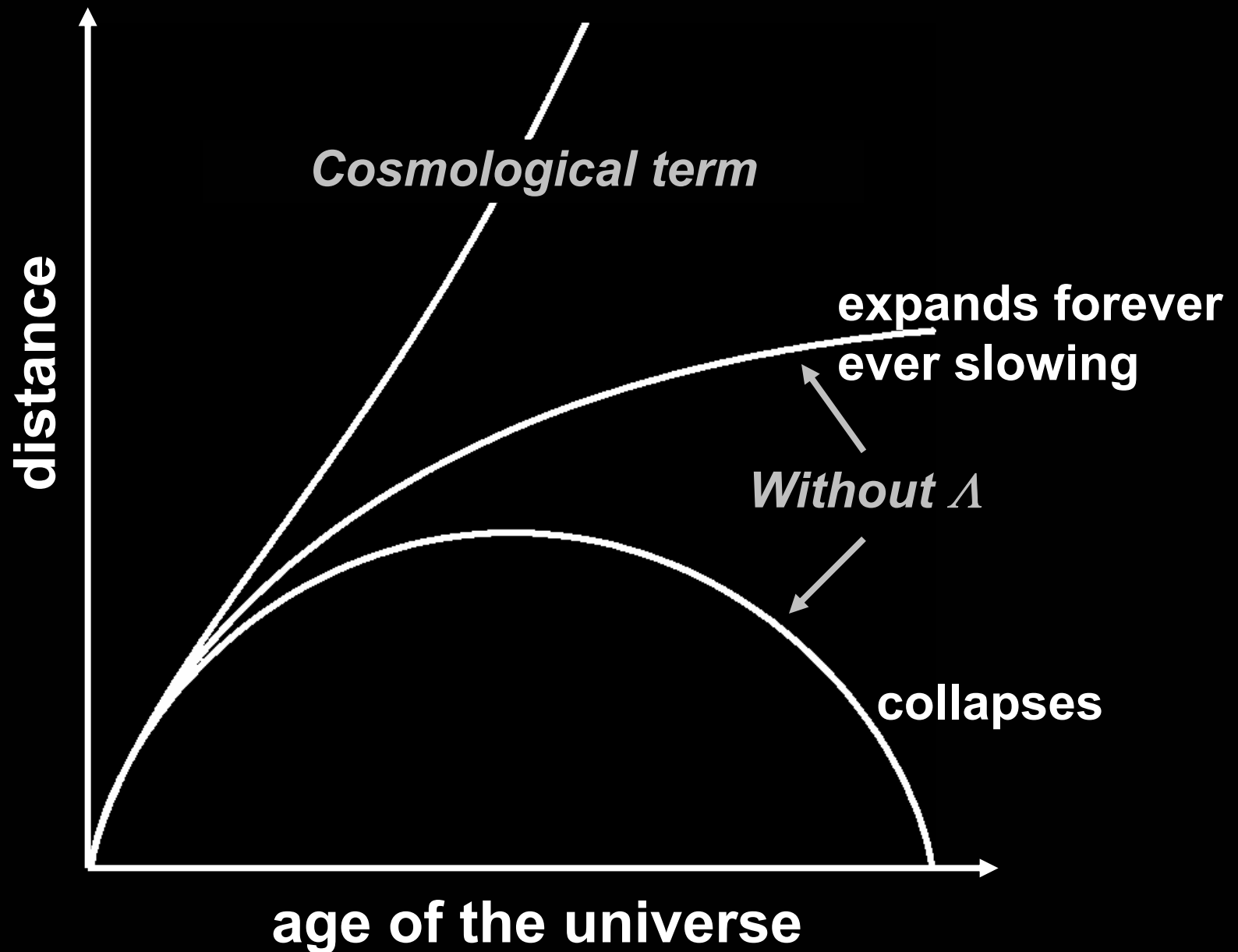
1929 Hubble discovered expansion of the Universe.

1934 Einstein called it "my biggest blunder."

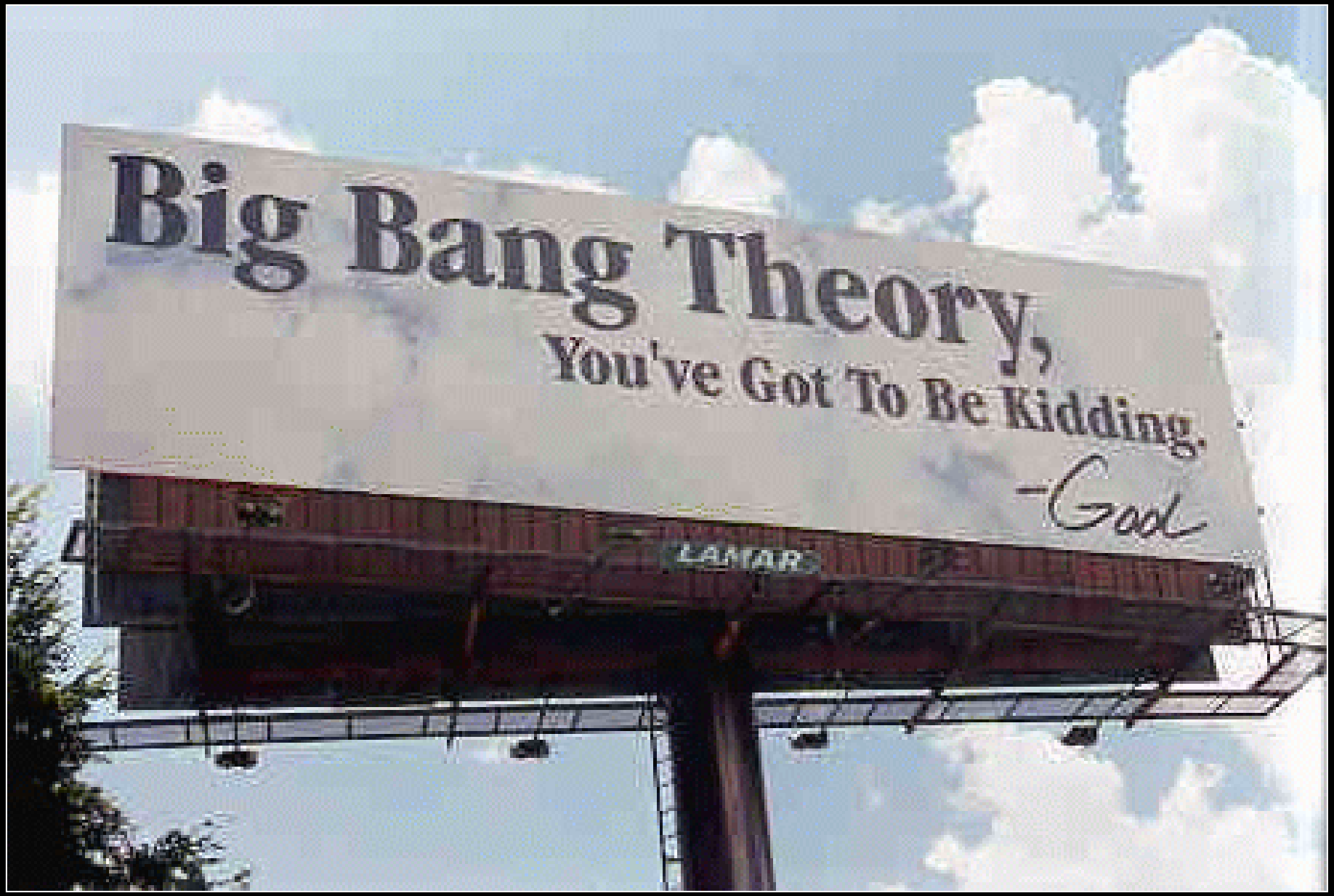
1998 Astronomers found evidence for it.



Our Cosmic Destiny

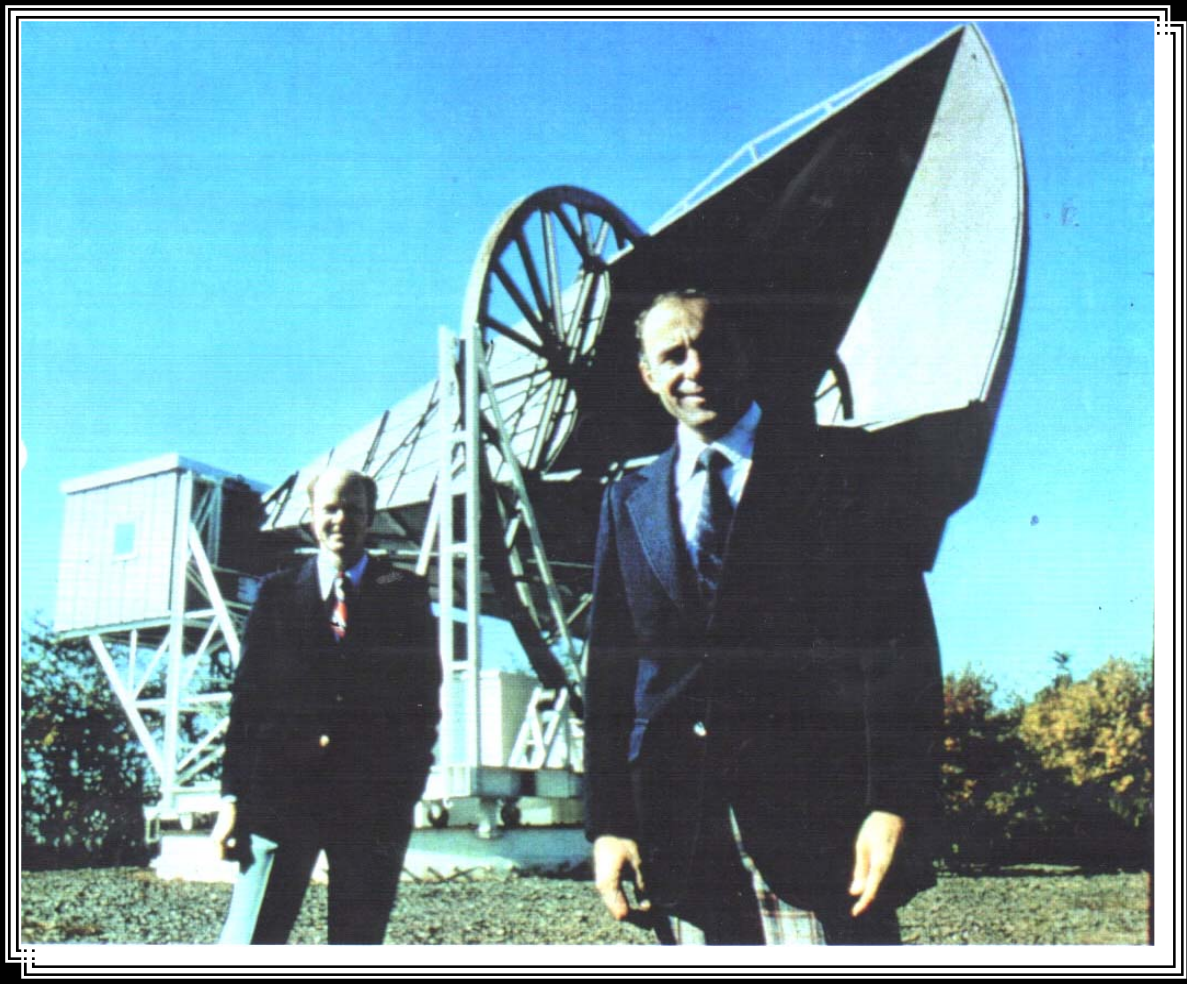


The Big Bang

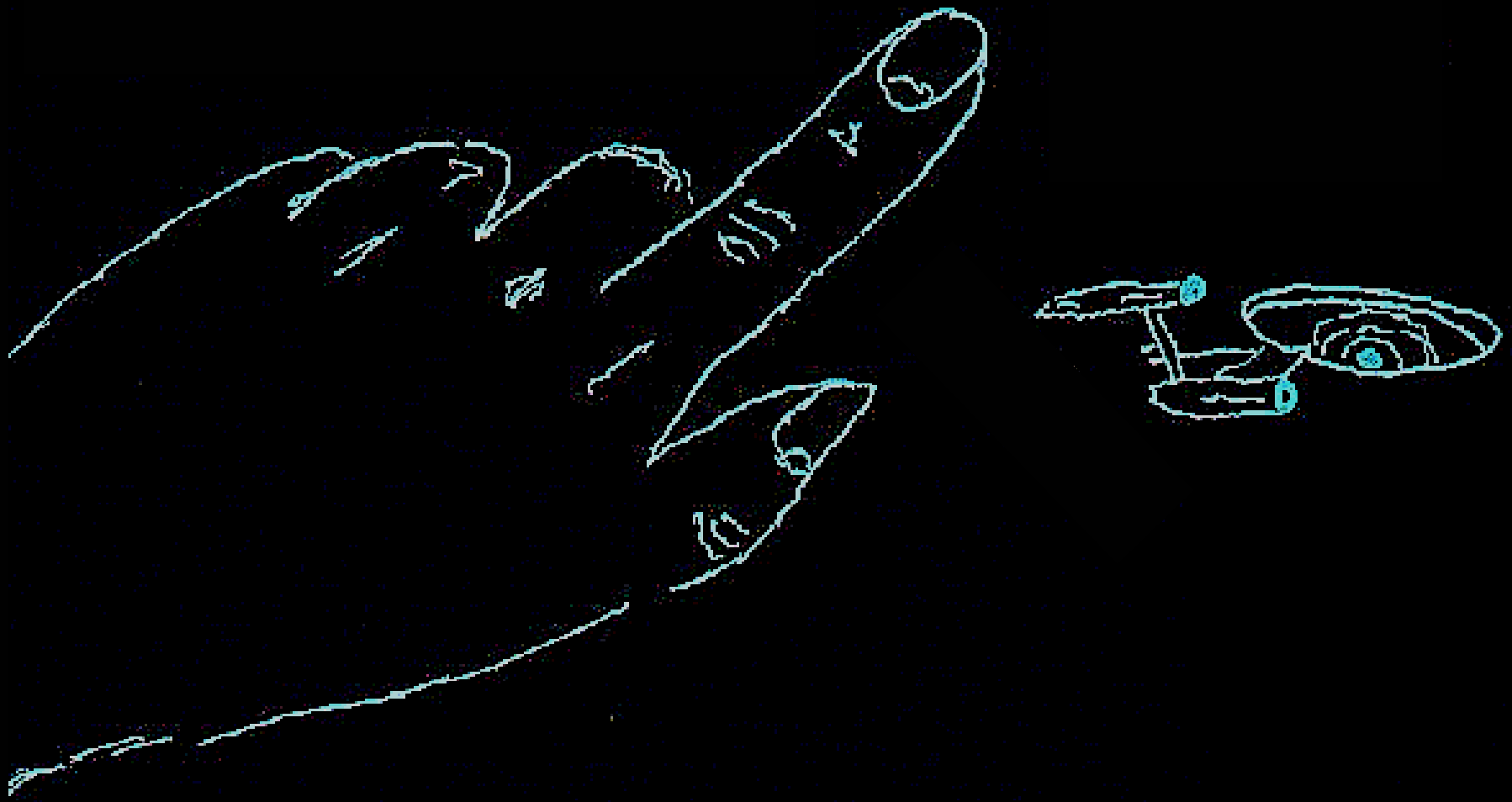


The universe
is radiant.

Arno Penzias
Robert Wilson
1965

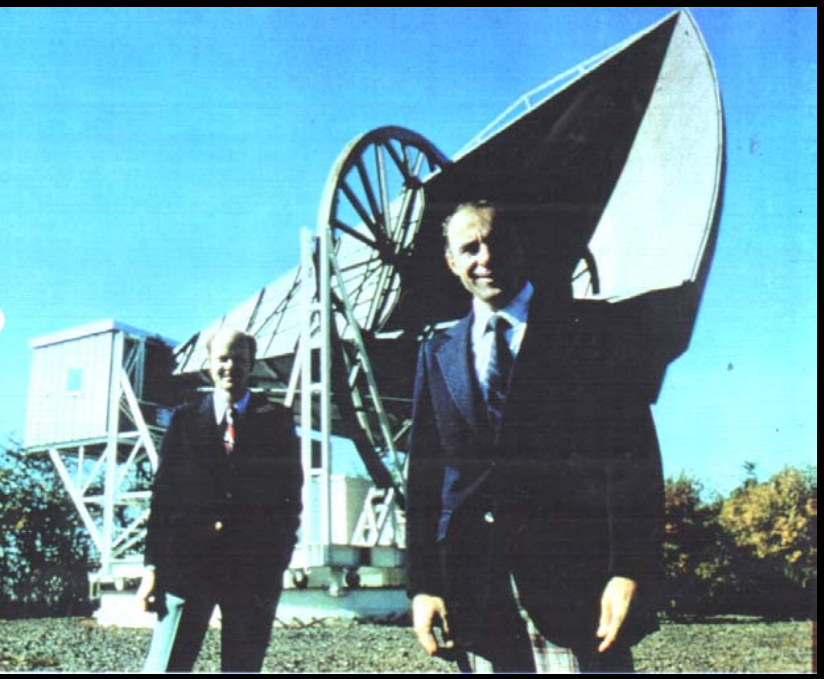


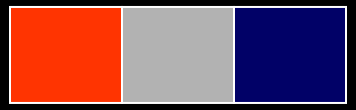
Cosmic background radiation



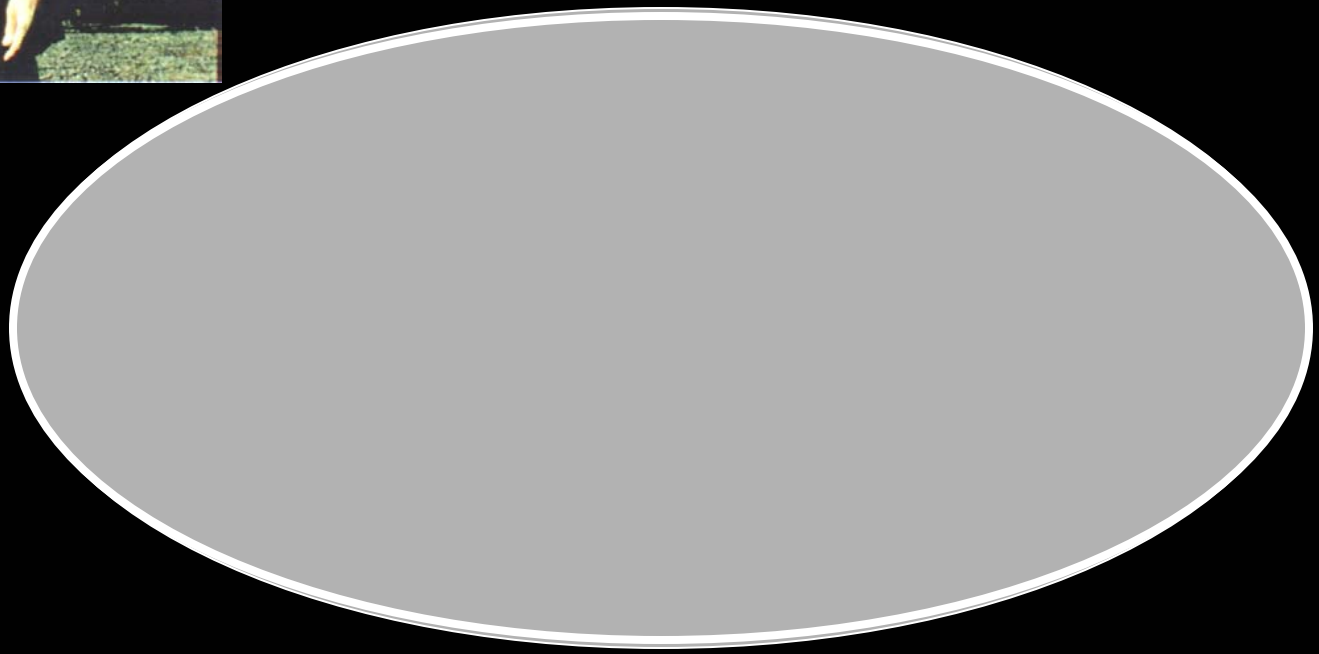
T = 3K = – 454° F

Cosmic Radiation ca. 1960s





2° 3° 4°



Cosmic Radiation ca. 1975

2.997° 3° 3.003°